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A Systematic Approach to Controlling the Sewer System

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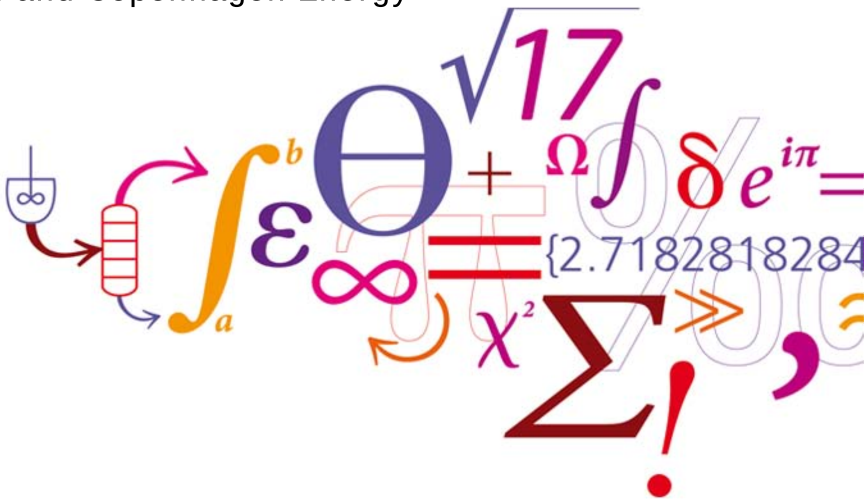
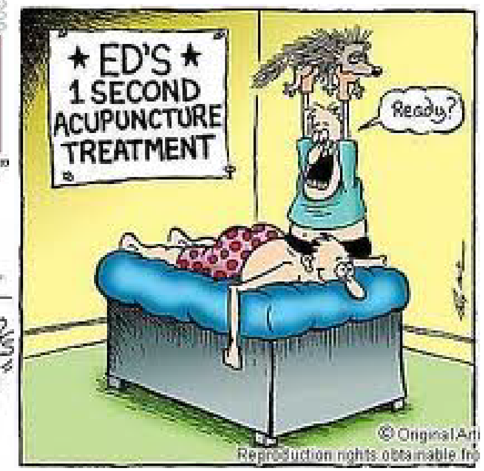


Outline

- What seems to be the problem?
  - Describing the symptoms and making the diagnose
- How can it be treated?
  - What do others do
- Can it be done in another way?
  - The research of my PhD

"Sounds good. No, wait – that's my iPod."



"Honestly, if there was a virtual prostate exam, don't you think I'd want to be the first to know?"

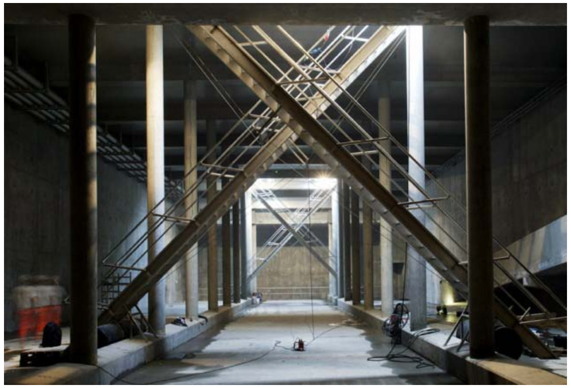
What seems to be the problem?

- When sewer systems or wastewater treatment plant (WWTP) are exceeded in capacity they spill (overflow) to a recipient or the terrain is flooded.


- The capacity of WWTPs are somewhat fixed – very expensive to increase
- The sewer systems are therefore changing to meet with more strict regulation and service levels

How can it be treated?

1. Build large basins
   – Is already being done



Basin at Skt. Annæ Plads in Copenhagen –

Has a capacity of 8000 m^3

2. Disconnect some of the rain water from the sewer system
   – Is also being done

Channels in Ørestad –

The rainwater from rooftops is lead directly into the channels

3. Optimize operation of where the water runs and maximize the use of the existing system (e.g. advanced system control)

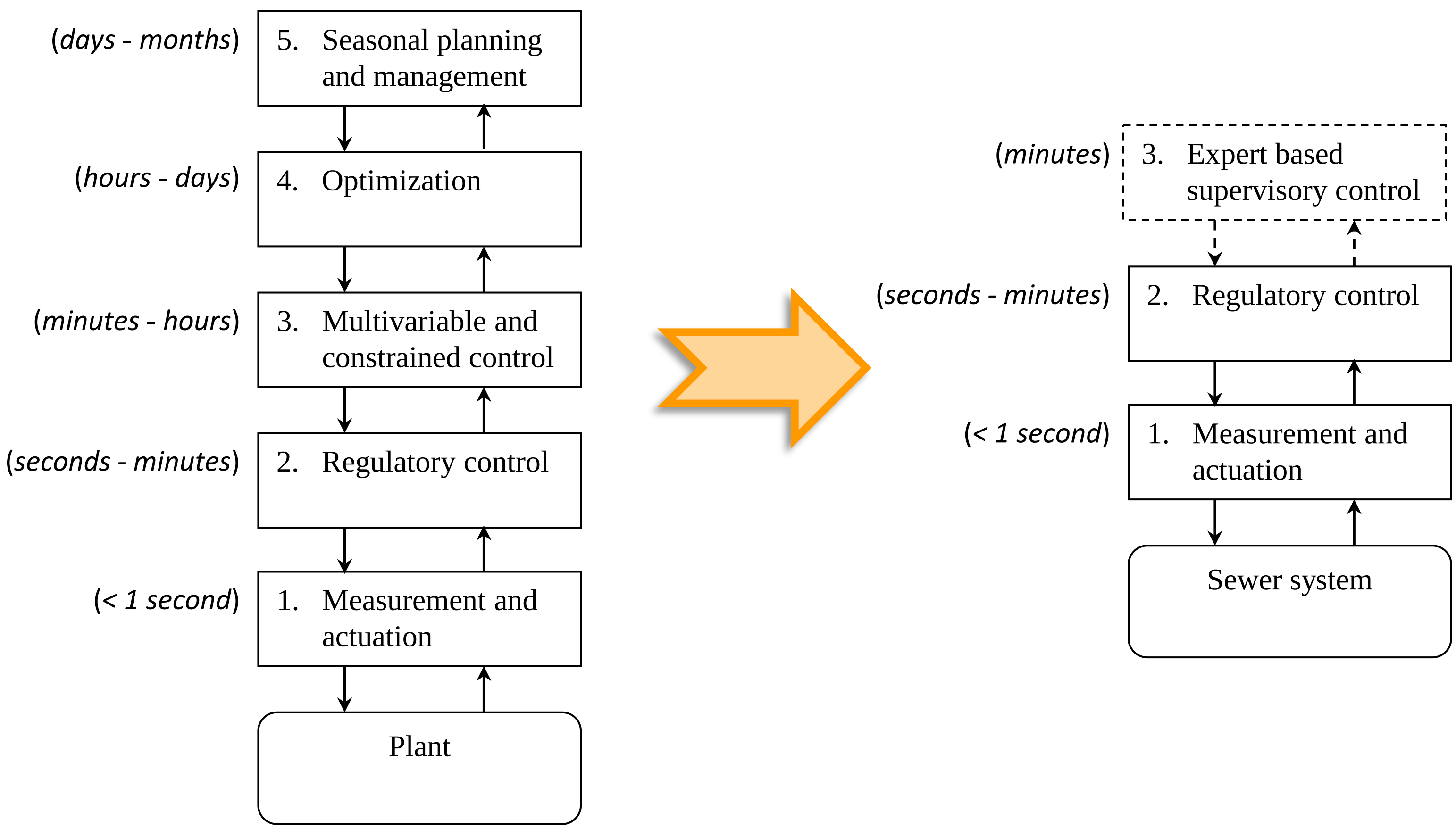
What types of control structures are implemented today?

- Research on what type off controls and control structures are implemented today and where is the research focused
  - Literature study
  - Survey (**DK, NL**, ES, AU, NO)

Typical control structure in the sewer system

Typical process control hierarchy in the chemical industry

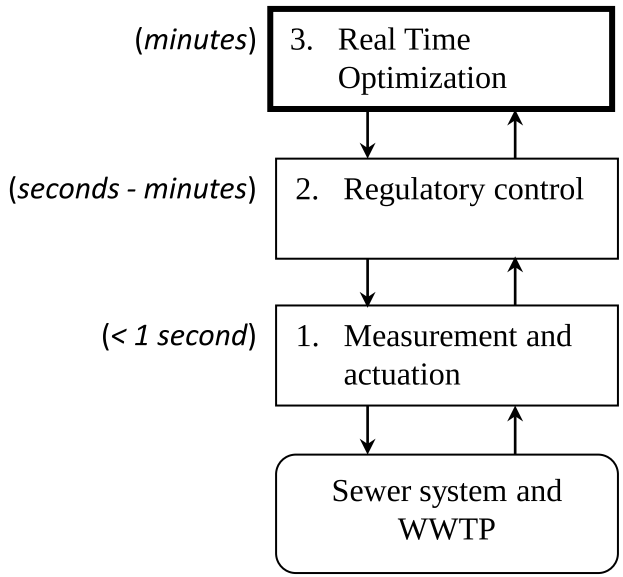
Typical control structure of a sewer system



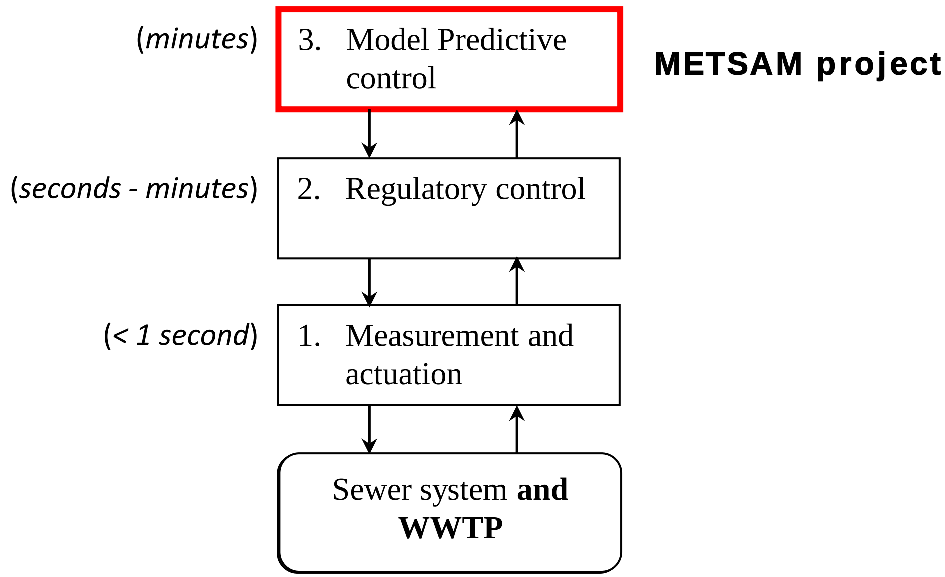
Based on Larsson and Skogestad, 2000

Advanced control structure in sewer systems in the Netherlands

Control structure of a sewer system and WWTP in the Netherlands (Hoeksche Waard)



Typical control structure in sewer system in Denmark



- In an effort to optimize the regulatory controls the rules have sometimes become very complex
- The control structure has evolved over time (spaghetti structure)

Preliminary survey results

The typical situation

- Some control loops implemented, but mainly at the regulatory level
- The control structures are made based on expert knowledge and setpoints are calculated from offline optimizations
- Advances are made with focus on systemwide optimization
- Little focus on the role of regulatory level

Can it be done in another way?

- Taking a systematic approach in the search for ideas

Step 1: Define objective

Step 2: Generate ideas

Step 3: Evaluate

Step 4: Implement/iterate

Step 1: Defining the objectives

- The aim is to minimize the “costs” in prioritized order
  - Cost of flooding
  - Cost of overflow
  - Cost of electricity consumption

Step 2: Generating ideas

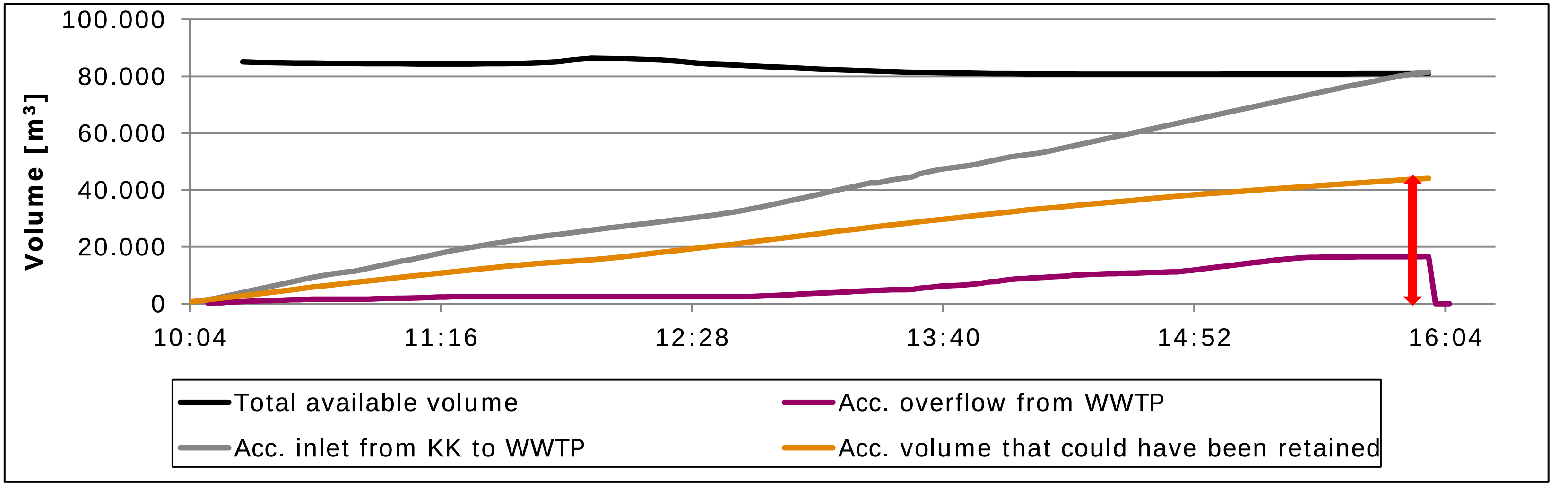
Analysis of operational data to answer the questions:

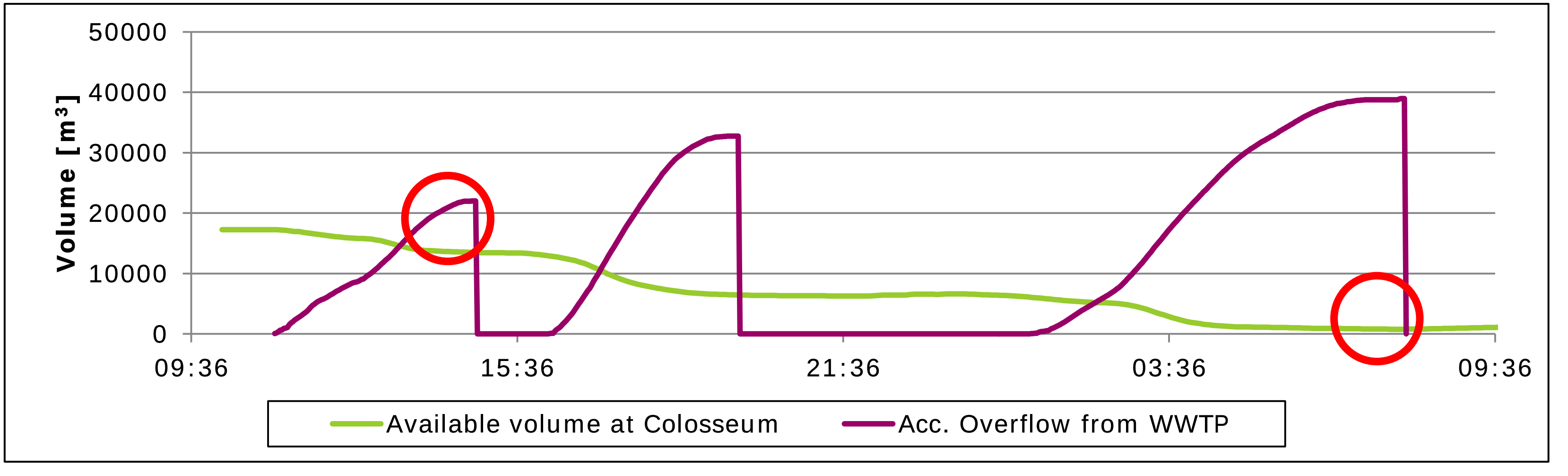
1. How much volume is left in the system when overflow occur?

2. What basins have free volume and at which locations does the overflows happen?

3. Can the free volume be utilized with a different operation of the system or is it limited by the design?

Operational data





Results from operational data

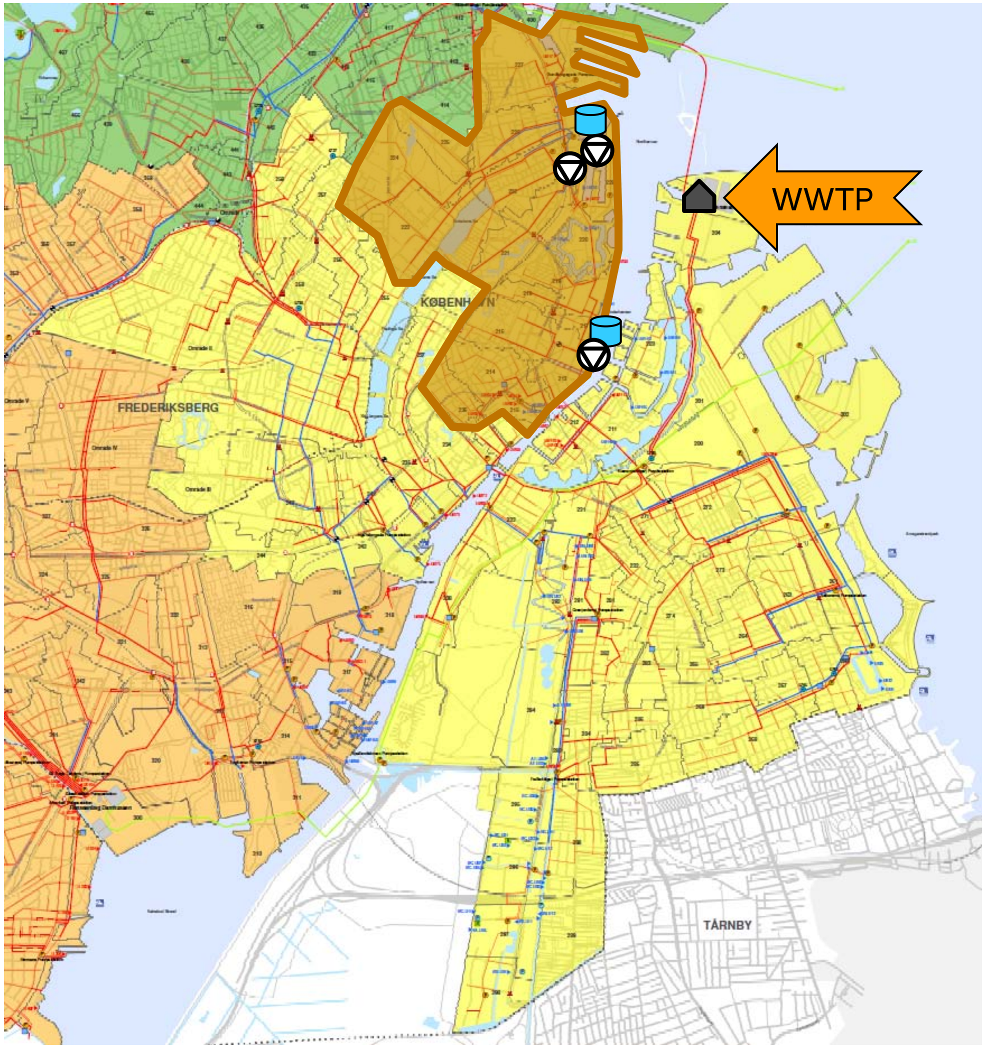
- Room for improving the operation of the system

- Need for multi objective control (flooding, overflow, electricity consumption)

- Need for model <u>predictive</u> control if the different overflows are to be penalized differently
  - An overflow from the sewer system is more costly than an overflow from the WWTP

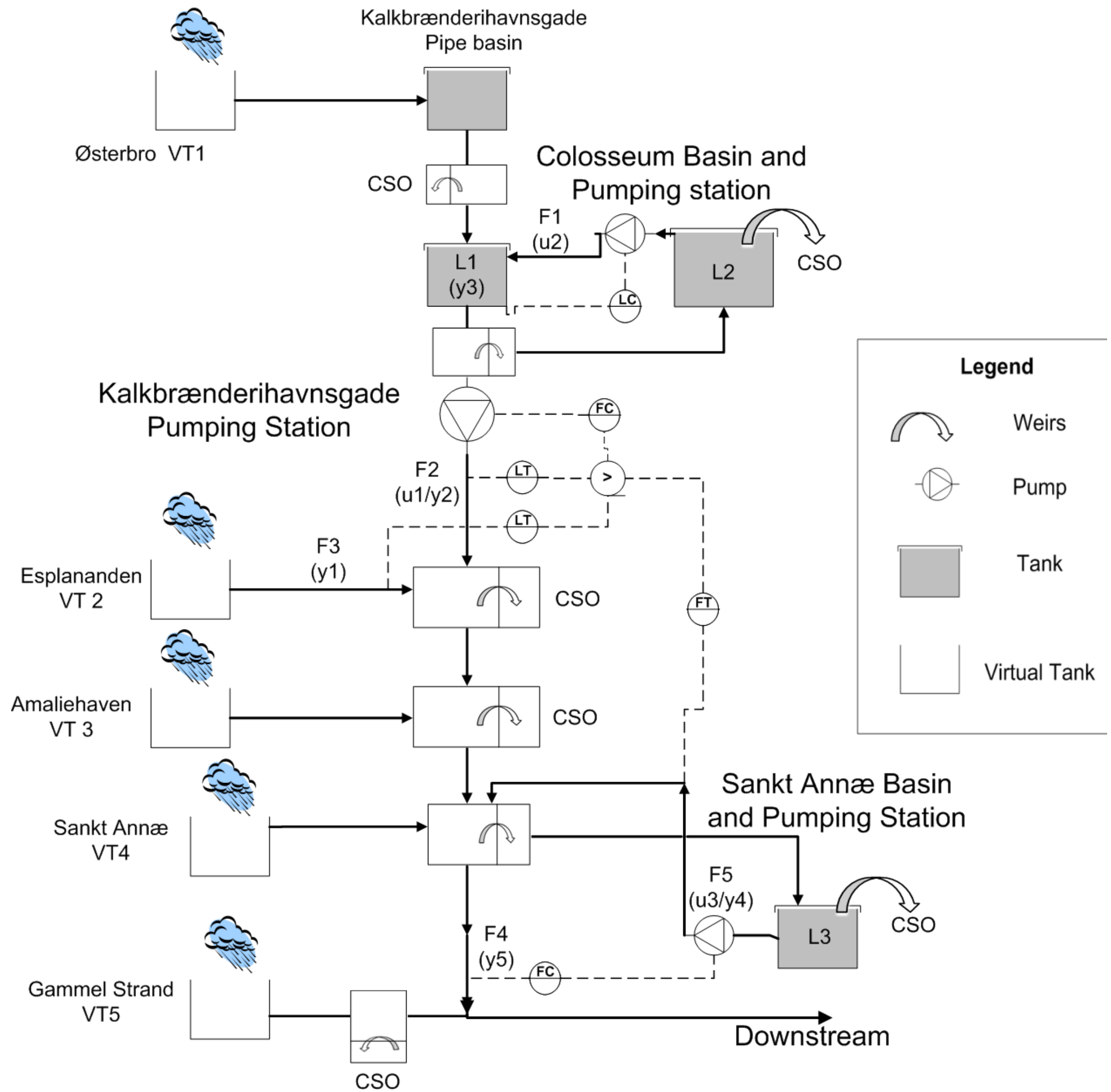
Case study

- Small catchment area
  - 2 basins
  - 3 pumping stations
  - 50 ha (0.5 km^2)
  - 135.000 PE
  - 6 combined sewer overflows (CSO)



The model

- A model is made in SimuLink using a "Virtual Tank" representation of the physical system
- Evaluation of existing control structure
- Generation of ideas for alternative control structure



Model equations

- Volume of the virtual tanks: $$\frac{dV_i}{dt} = q_{in} + I_{eff} - q_{out}$$

- Outflow from the virtual tanks: $$q_{out} = \beta_i V_i$$

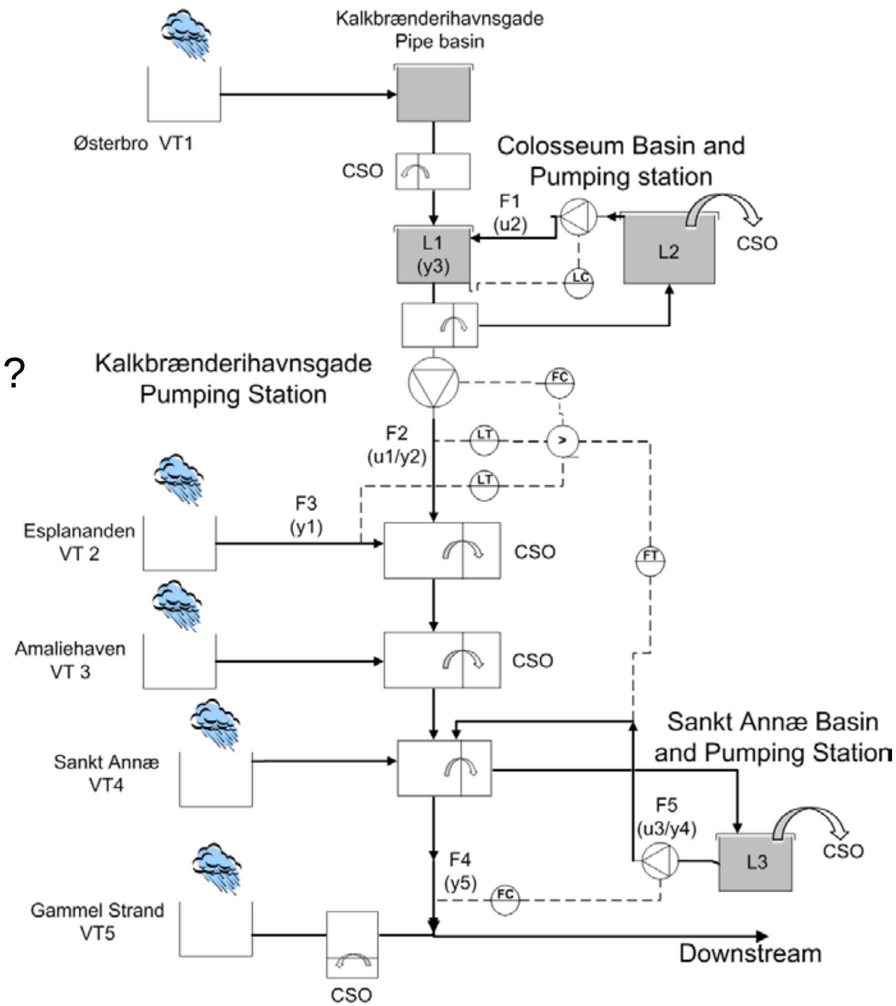
- Weirs: $$q_{out} = \begin{cases} q_{in} & if \;\; q_{in} \leq q_{max} \\ q_{max} & otherwise \end{cases}$$

- Overflows: $$q_{overflow} = \begin{cases} 0 & if \; \mathrm{V} \leq V_{max} \\ q_{in} - q_{out} & otherwise \end{cases}$$

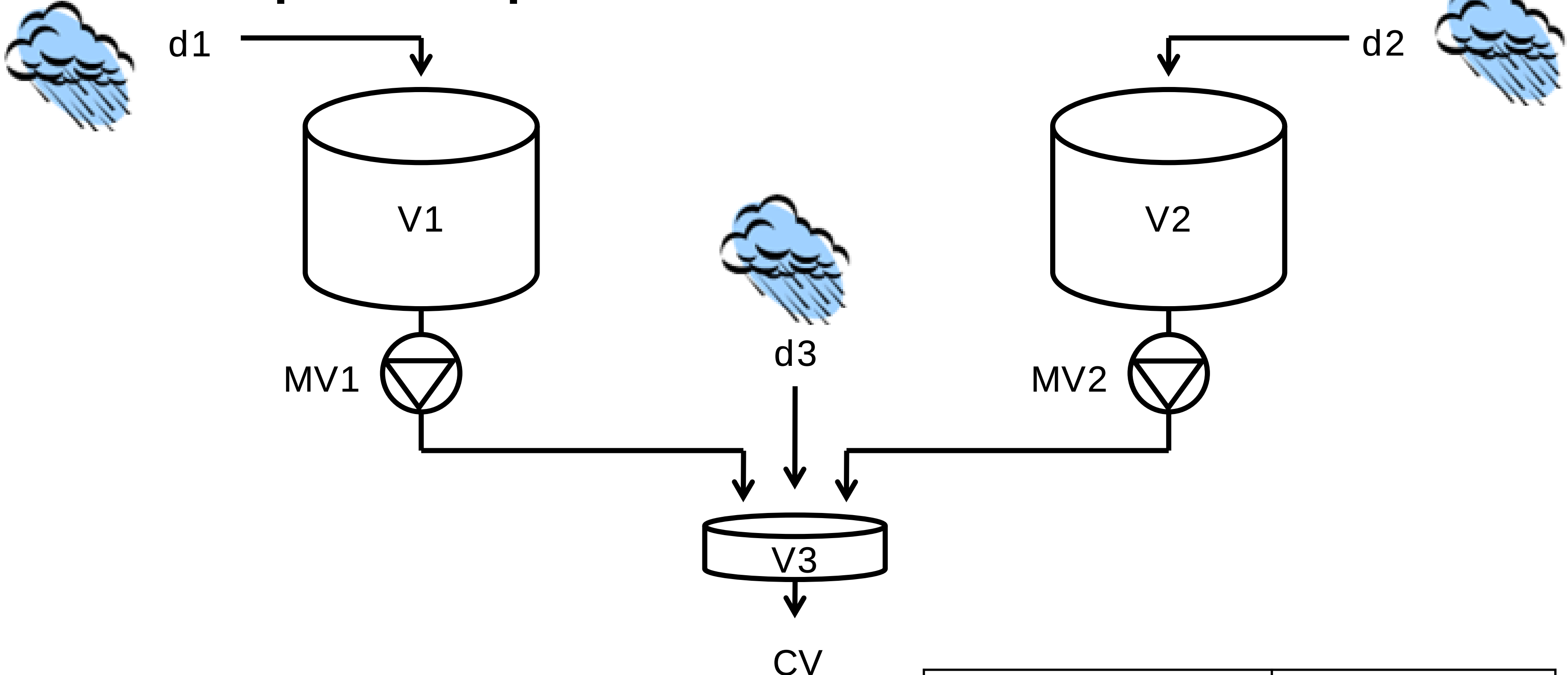
Pairing between actuators and controlled variable

- The actuators are fixed and cannot easily be changed
- How can the actuators be paired with the measurements?
- What is the control degrees of freedom?

… **What is steady state for the system?**



Determining the control degrees of freedom – A simple example



A system with no degrees of freedom when large disturbances (rain)

And two degrees of freedom when small disturbances (rain)

$Q_{small\ rain}$ / $Q_{dry\ weather}$	$\left.\frac{\partial CV}{\partial MV}\right\|_{Q_{dw}} \nearrow +$
$Q_{intense\ rain}$	$\left.\frac{\partial CV}{\partial MV}\right\|_{Q_{rain}} \sim 0$

Steady state

- There is no such thing as steady state for the sewer system during rain
- The controls cannot fully reject disturbances – therefore the need for retention basins
- Only during low intensity rain events do we have the maximum control degrees of freedom

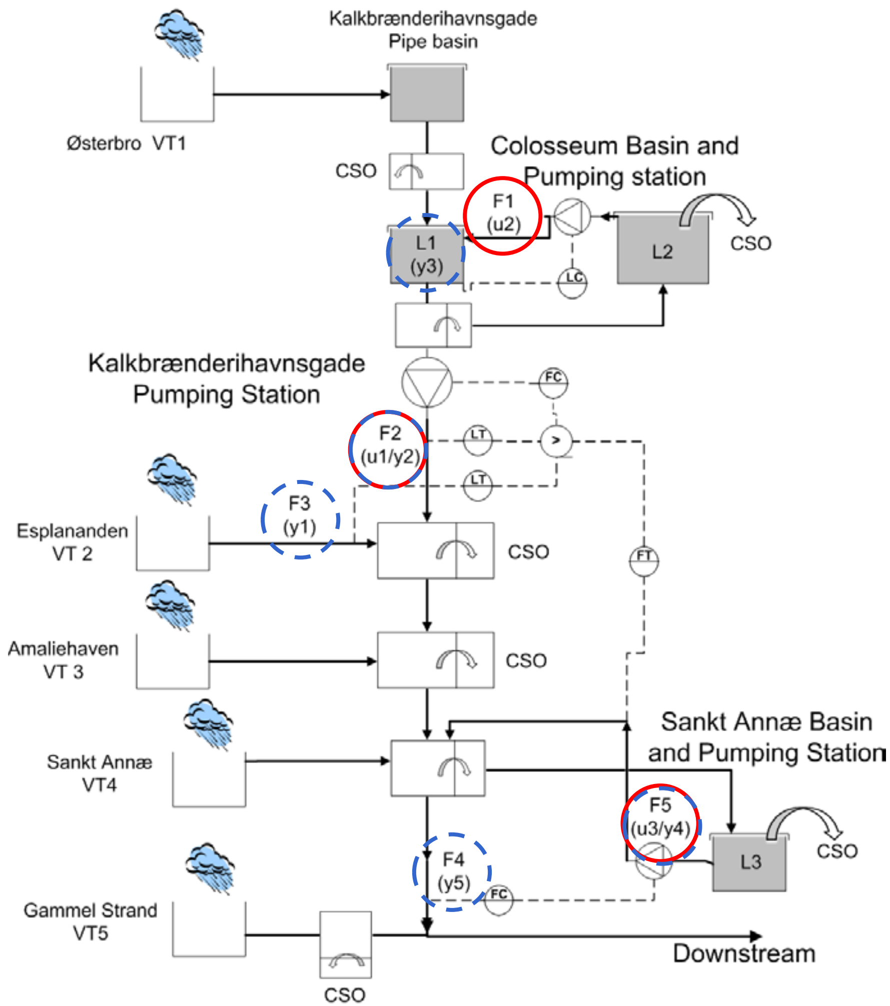
Linearizing the existing control structure

- 3 inputs – 5 outputs

$$x_{k+1} = [0]x_k + [-1 \quad 1 \quad 0]u_k$$

$$y_k = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} x_k + \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 1 \end{bmatrix} u_k$$

- Feed through ⇒ No states ⇒ No state feedback control
- RGA is diagonal ⇒ input-output
- Disturbances are rejected using the supervisory layer (offline optimization)
- An alternative is online optimization



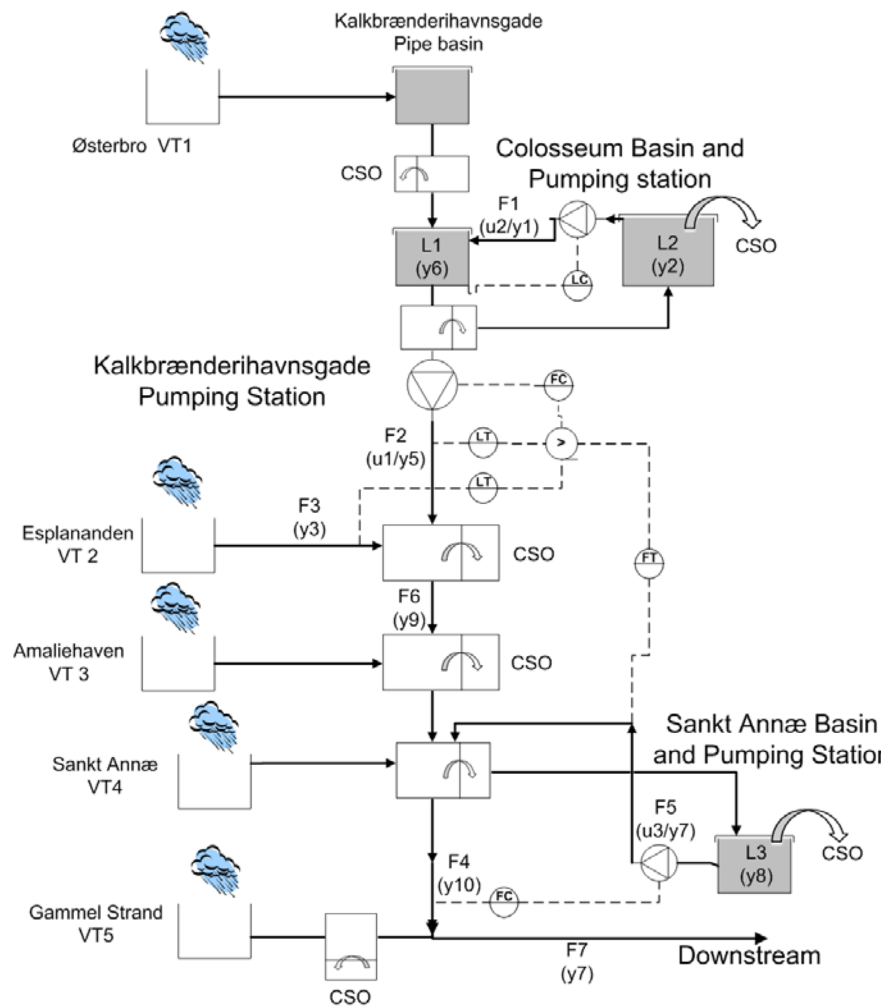
Alternative control structure at the regulatory layer

- The actuators are still fixed (3)
- 10 measurements

- To determine the possible controlled variables the condition numbers for a 3-times-3 system are calculated

MV	u1	u2	u3	Cond. No.
CV	F2/F6	F1	F7/F4	2.618
	F2/F6	F1	F5	1.000
	F4/F7	F1	F5	2.618
	L1	L2	L3	2.618

- Only the pairing where the MV's are related to the levels in the basins provide a possible feedback structure



Preliminary findings

- There is a potential for reducing the overflow from the wastewater system by better utilization of the volume capacity in the sewer systems

- Changing the operation will decrease the total amount of overflow, but can be at the expense of a increase in the number of overflow from the sewer system – unless this is included in the optimization

- The system will saturate during intense rain – the control degrees of freedom is not constant

- The existing control structure cannot reject the disturbances at the regulatory level (no feedback)

- Alternative pairing at the regulatory layer can provide feedback loops.

  An evaluation must be done using total overflow and surface flooding as evaluation parameters.

The investigation continuous…

Thank you for your attention

References
Larsson, T. and Skogestad, S. *Plantwide control – a review and a new design procedure*. Modeling, Identification and Control, 2000, vol. 21. NO. 4, 209 – 240.

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